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EARLY UNIVERSE BARYOGENESIS

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Abstract. We discuss the scalar field condensate baryogenesis model, which is among the preferred today baryogenesis scenarios, compatible with inflation. According to that model the baryon excess in the Universe results from the decay of a scalar condensate, carrying a baryon charge, at later stages of Universe evolution ($T << 10^{15}$ GeV). The condensate itself is generated at the inflationary stage.

We update the parameters of the model and analyze numerically the post inflationary evolution of the scalar condensate. We determine the value of the generated baryon asymmetry, after the decay of the condensate.

The numerical analysis confirms the main result of the analytical and numerical estimations, obtained in previous studies, that the observed value of the baryon asymmetry can be obtained in the discussed model of baryogenesis. The dependence of the generated baryon density on the model's parameters is obtained.

1. INTRODUCTION

The generation of the observed baryon asymmetry β is one of the yet unsolved problems of cosmology. There exist numerous baryogenesis scenarios, the most famous among them being GUT, electroweak and scalar field condensate scenarios.

The most natural versions of GUT and electroweak baryogenesis scenarios were already ruled out by experimental data. Therefore, we discuss the scalar field condensate baryogenesis model, which is among the preferred today baryogenesis scenarios, compatible with inflation.

Attractive features of the model are: The model is compatible with inflation, there is no problem of insufficient reheating, there is no washing out of the baryon excess at EW phase transition, the model provides natural generation of a small β.

2. BARYON ASYMMETRY OF THE UNIVERSE

There exist strong predominance of matter over antimatter in our Galaxy indicated from the Cosmic Ray and Gamma Ray experiments.

Cosmic Ray search for $\bar{p}$ and antinuclei on baloons and spacecraft found: $\bar{p}/p \sim 10^{-5}$ at $E < 2$ GeV, and $\bar{p}/p \sim 10^{-4}$ at $E > 2$ GeV. So, antiprotons detected in primary cosmic radiation can be totally due to interactions of the primary CR particles with the interstellar medium.

Antinuclei have not been detected, only the folowing upper limit was obtained (see e.g. Saeki et al., 1998).: $\bar{H}e/He < 1.7.10^{-6}$.

Thus cosmic ray data indicate that there are no antimatter objects within a radius of 1 Mpc.

Gamma Ray data, namely the absence of the annihilation feature expected from the borders between matter and antimatter regions, points that antimatter objects, eventually present in our cluster of galaxies, should be negligible.

Hence, in our near vicinity the baryon asymmetry reads:

$$\beta = (N_B - N_{\bar{B}})/N_\gamma \sim N_B/N_\gamma = \eta,$$

where N_B is the number density of baryons, N_γ is the number density of photons.

The observaional value of the baryon-antibaryon asymmetry in our neigbourhood is:

$$\beta \sim \eta \sim 6.10^{-10}$$

There are different ways to determine the baryonic density, also denoted as $\Omega_b h^2 = 3.65.10^7\eta$. The most popular and precise among them are:

BBN precision determinations ($z \sim 10^9$): The concordance b/n predicted and extracted from observations of primordial abundances of D, He-3, He-4, Li-7 measures the baryon content of the Universe (see e.g. Cyburt et al., 2003; Cuocco et al., 2003). The extreme range of it being: $0.016 \leq \Omega_b h^2 \leq 0.025$.

D measurements towards low Z QAS (Lyman limit systems - LLS) ($z \sim 3$) + BBN (see e.g. Burles et al., 2001; Kirkman et al., 2003):

$$\Omega_b h^2 = 0.0216^{+0.0020}_{-0.0021}$$

for $D/H = (2.78^{+0.44}_{-0.38}) \times 10^{-5}$.

CMB determinations($z \sim 1000$):
The CMB anisotropy measurements after WMAP are providing the most precise value for the baryon density, namely (see e.g. Spergel et al., 2003):

$$\Omega_b h^2 = 0.0224 \pm 0.0009.$$

The explanation of the generation of the observed baryon density value and its sign is the main aim of the contemporary baryogenesis scenarios.

3. SCALAR FIELD CONDENSATE BARYOGENESIS MODEL

The model has been first proposed by Dolgov and Kirilova (see e.g. Dolgov and Kirilova, 1991) and discussed in detail in (see e.g. Kirilova and Chizhov, 2000). The model was based on the Affleck and Dine baryogenesis scenario. Essential characteristics of the model:

* Complex scalar field ϕ, carying baryon charge $B \neq 0$, is present at inflation.
The condensate of the baryon carrying scalar field $< \phi > \neq 0$ is formed as a result

of the enhancement of quantum fluctuations of the field (see e.g. Vilenkin and Ford, 1982; Linde, 1982; Bunch and Davies, 1978):

$$< \phi^2 >= H^3 t/4\pi^2$$

In the case when the length of the fluctuations exceeds the horizon, they cannot be distinguished from a homogeneous classical field with amplitude $< \phi^2 >^{1/2}$.

* Baryon charge violation at micro distances at the inflationary stage:
As a result of the baryon charge violation (BV) at large ϕ due to BV self-interaction terms in the potential $U(\phi)$ a condensate of a baryon charge (stored in $< \phi >$) is produced during the inflationary stage $B \sim H_I^3$.

$$U(\phi) = m^2\phi^2 + \frac{\lambda_1}{2}|\phi|^4 + \frac{\lambda_2}{4}(\phi^4 + \phi^{*4}), \tag{1}$$

where $m \ll H_I$, $\lambda_i \sim \alpha$, $m \sim 10^2 \div 10^4$ GeV. The initial values: $\phi_o^{max} \sim H_I \lambda^{-1/4}$ and $\dot{\phi}_o = 0$ are obtained from the natural assumption that the energy density of ϕ at inflation is $\sim H_I^4$.

3.1. EVOLUTION OF ϕ AND B AFTER INFLATION

At the end of inflation there exist 2 scalar fields: the inflanton ψ and ϕ, which begin to oscillate about their global minima, when $H \leq m$. As far as $m_\psi > m_\phi$, the inflanton oscillations start first:
$\psi = m_{PL}(3\pi)^{-1/2}\sin(m_\psi t)$, $H = 2/(3t)$; $\rho_\psi > \rho_\phi$.
It further diminishes with expansion according to $\rho = m_\psi^2 M_{Pl}^2[(R_{os}/R]^3$ Therefore we make the natural assumption that the inflanton energy density dominates the Universe.

Then in the expanding Universe ϕ satisfies the equation:

$$\ddot{\phi} - a^{-2}\partial_i^2\phi + 3H\dot{\phi} + \Gamma\dot{\phi} + U'_\phi = 0, \tag{2}$$

At $\phi >> m$ ϕ oscillates with a decreasing amplitude, as (see e.g. Dolgov and Kirilova, 1990; Kirilova and Chizhov, 1996) due to:
(a) Universe expansion
(b) particle production by the oscillating with frequency ω scalar field, coupled to fermions $g\phi\bar{f}_1 f_2$: Hence, ϕ is damped: $\phi \to \phi\exp(-\Gamma t)$, where $\Gamma = \alpha.\omega$, $g^2/4\pi = \alpha$, $\omega \sim \lambda^{1/2}\phi_i(x)$.

In this toy model we have accounted for the damping due to particle creation adiabatically. B is damped correspondingly, as well, since $B = -i\lambda_2(\phi^4 - \phi^{*4})$.

If ω is a decreasing function of time there is slow damping, and therefore B could survive until B-conservation epoch t_b, corresponding to $\phi \sim m$.

At $\phi \sim m$ ϕ decays. The amplitude of ϕ decreases due to particle creation till t_b epoch. $\phi \sim m$ marks the beginning of the B-conservation epoch t_b during which ϕ decays with nonzero average baryon charge into quarks and leptons $\phi \to q\bar{q}l\gamma$. This baryon charge transfered to quarks dictates the observed today baryon asymmetry.

In fact the baryon charge transfered to quarks at the baryon conservation epoch should be diminished by the entropy resulting from the reheating of the Universe due to the inflanton decay.

4. THE NUMERICAL ANALYSIS - DESCRIPTION AND RESULTS

We have provided a numerical analysis of the scalar field evolution after the inflationary stage till the field's decay. We have used Runge-Kutta 4th order scheme with step $h = 10^{-7} - 10^{-8}$. The following range of the model's parameters was analyzed: $10^{-2} \leq \lambda \leq 5 \times 10^{-2}$, $10^{-3} \leq \alpha \leq 10^{-2}$, $10^{6} \leq H \leq 10^{13}$, $100 \leq m \leq 2000$.

In Fig. 1, the baryon charge carrying scalar field is presented. The upper part gives the evolution of the field without particle creation account, the lower one – with the account of the particle creation processes. Depending on the value of $\Gamma \sim \phi \sim \alpha H$ the damping of the field may be more or less strongly expressed.

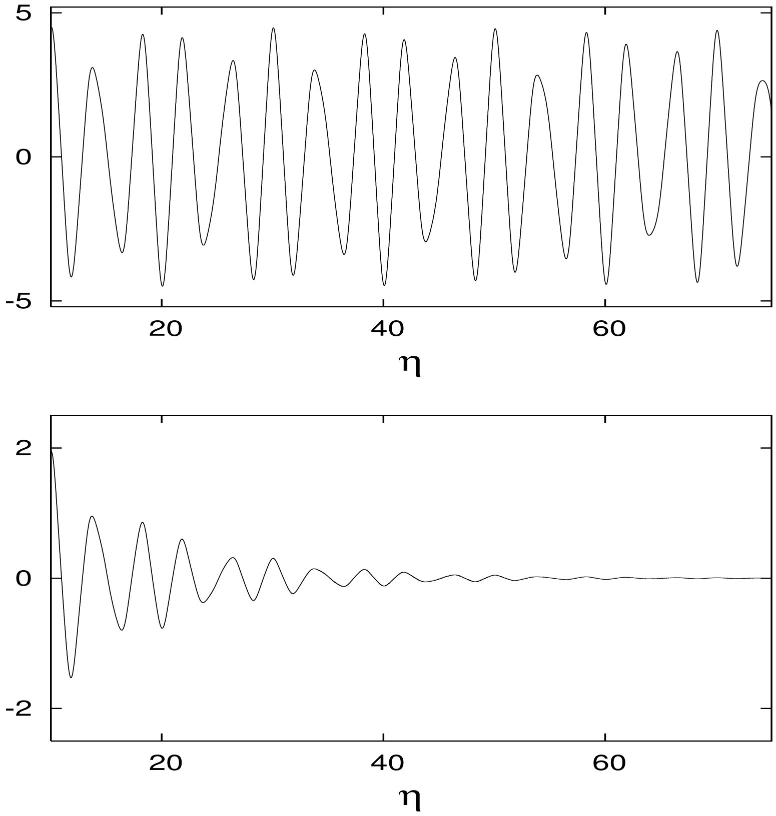

Figure 1: The evolution of the field $\phi_1(\eta)$ for $\lambda_1 = \alpha = 10^{-2}$, $\lambda_2 = 10^{-3}$, $m = 350$ GeV, $H_I = 10^{12}$ GeV $\phi_o = H_I \lambda^{-1/4}$, and $\dot{\phi}_o = H_I^2$.

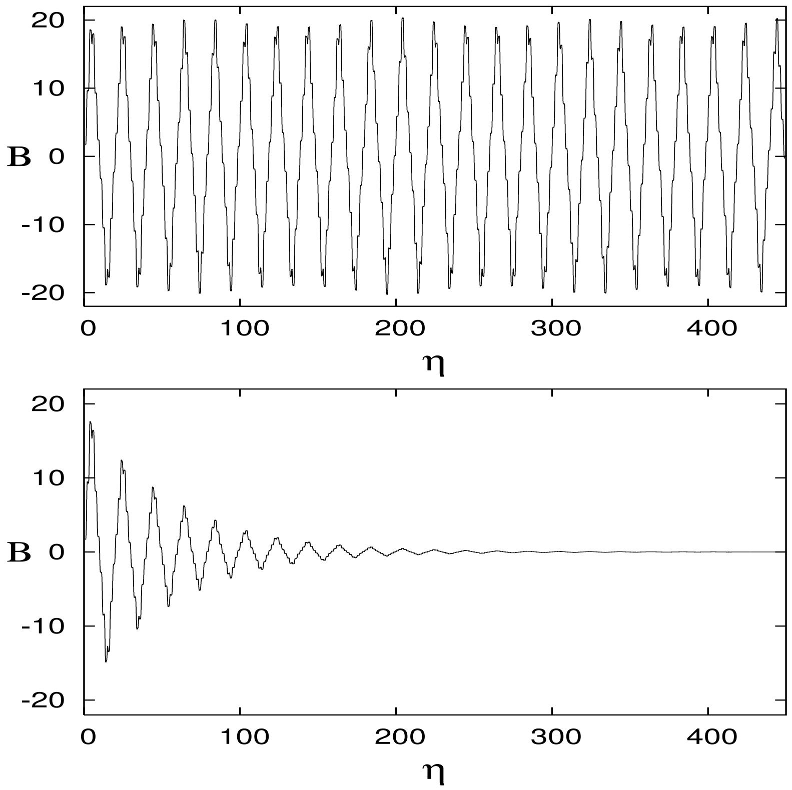

Figure 2: The evolution of the baryon charge $B(\eta)$ contained in the condensate $< \phi >$ for $\lambda_1 = 10^{-2}$, $\lambda_2 = \alpha = 10^{-3}$, $m = 350$ GeV, $H_I = 10^{12}$ GeV $\phi_o = H_I \lambda^{-1/4}$, and $\dot{\phi}_o = H_I^2$.

As illustared, particle creation may lead to a considerable decrease of the field's amplitude for large α or/and large H values, which reflects finally into the decrease of the baryon charge carried by the condensate. This is easy to understand having in mind that, $\Gamma \sim \alpha H$.

The evoluition of the baryon charge contained in the condensate and the field are shown in the Fig. 2. The upper curve presents the evolution of the baryon charge of the condensate in the case when particle creation is negligible, the second one presents the more realistic situation, when the particle creation processes are accounted for.

Due to the oscillatory character of B, the value of the generated asymmetry is very sensitive to the parameters of the model, as well as to the numerical methods used, and therefore, the problem requires further precise numerical studies. On the first place, due to the extreme sensitivity of the generated baryon value to Γ, it is necessary to account more accurately for the damping due to particle creation. Here we have used the analytical estimation, obtained e.g. in Dolgov and Kirilova (1991) for the frequency of the field.

Future more realistic models of baryogenesis should obtain selfconsistently the frequency and correspondingly Γ from the exact numerical analysis of the fields evolution. Our preliminary results concerning this show that the numerically calculated oscillation frequency of the field may be quite different from the assumed, analytically estimated one, used in the adiabatical approximation of the particle creation.

5. RESULTS AND CONCLUSIONS

We have provided more precise numerical analysis of the scalar field condensate baryogenesis model.

The range of parameters H, m, T_R, was updated according to the current observational cosmological constraints.

We have numerically analyzed the evolution of the baryon charge carrying scalar field using the exact kinetic equations. In previous studies it was studied semianalytically.

We confirm the most essential result of the original studies that the model can serve as a successful baryogenesis model, compatible with inflation. We have determined the values of model's parameters required for generating the observed B value. The analysis has shown that for a natural range of the model's parameters the observed value of the baryon asymmetry can be obtained.

This toy model can be further improved by providing more precise account for the particle creation processes, which play essential role for the determination of the final baryon value.

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